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Title: Understanding Asymmetry Formation in Dusty Proto-Planetary Disks with  
Dust-Growth Model

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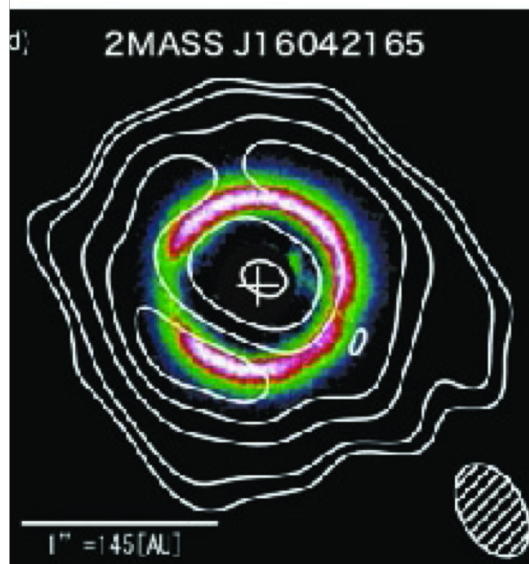
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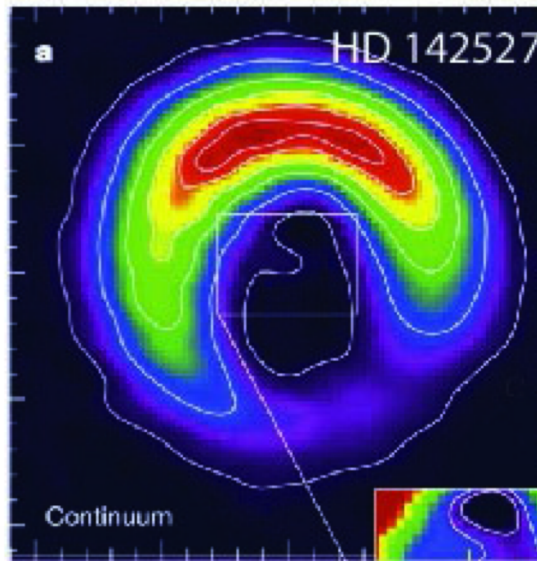
# Understanding Asymmetry Formation in Dusty Proto-Planetary Disks with Dust-Growth Model

Shengtai Li

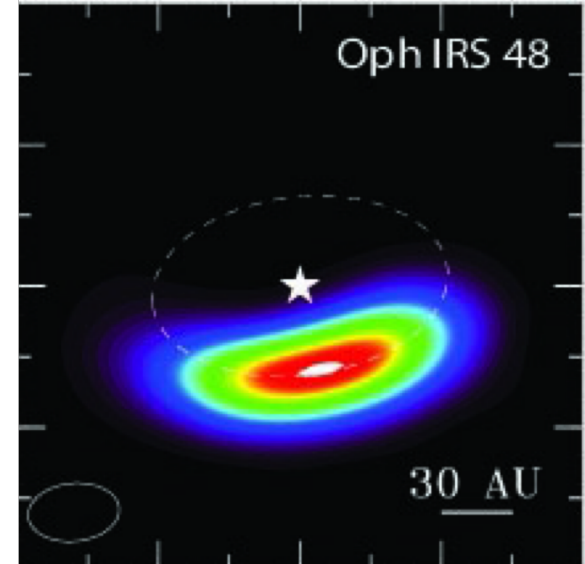
# Asymmetric Proto-Planetary Disks Observed by ALMA Telescope



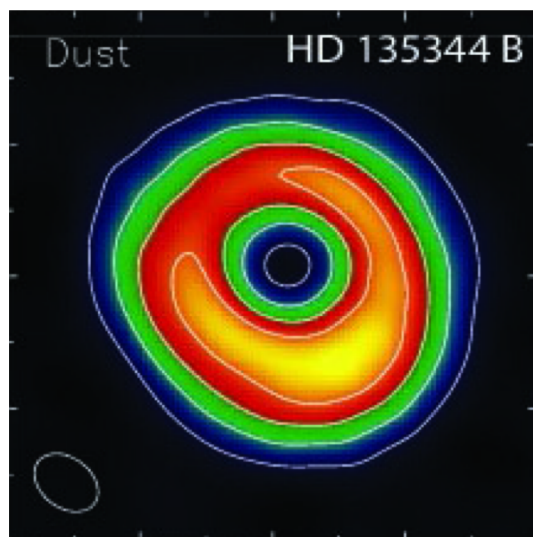
Hayama et al. (2012)



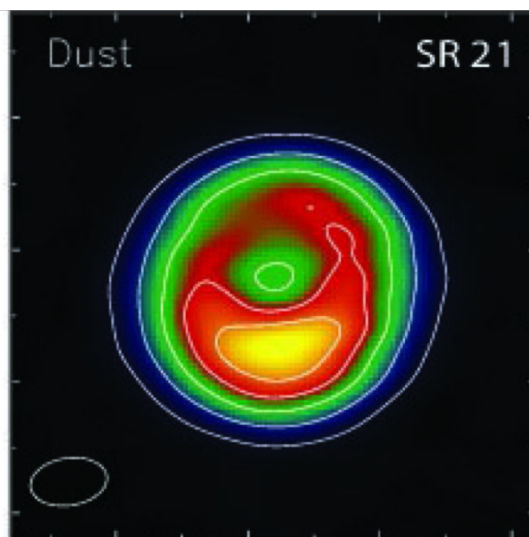
Casassus et al. (2013)



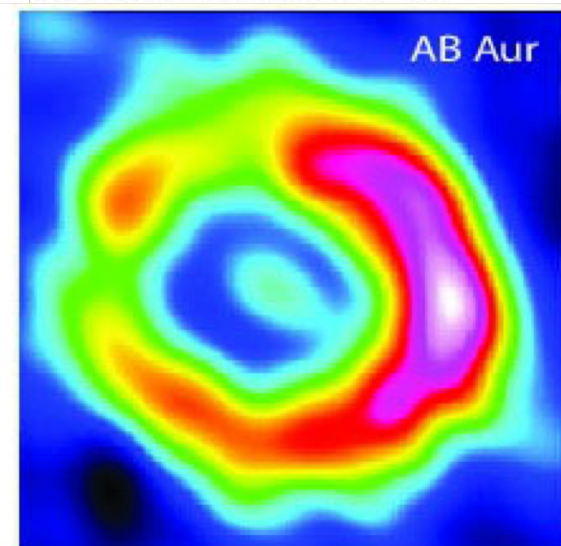
van der Marel et al. (2013)



Pérez et al. (2014)



Pérez et al. (2014)



Rodríguez et al. (2014)



# Numerical Modeling and Simulations for these Disks

- The coupled dust and gas is necessary because all the observations are mainly dust emission and the gas distribution is quite different from the dust distribution in a proto-planetary disk.
- The multi-species dust simulations are also necessary because for different sizes of dust particles, the density distribution and brightness emission is different.
- The dust growth via dust coagulation is necessary because the dust size distribution and transportation is a dynamic process

# Development of Coupled Gas + Dust code for Multi-Dust Species

- Using one-fluid approach to simulate the two-fluid dusty flow.
  - Treat the mixture of the dust and gas as a single fluid.
  - Limit the stiff drag term between dust and gas to the equations of drift velocity
- Using two-fluid solver to solve the one-fluid equations with slight change
  - Using the legacy code
  - Easy to implement with available Riemann solver

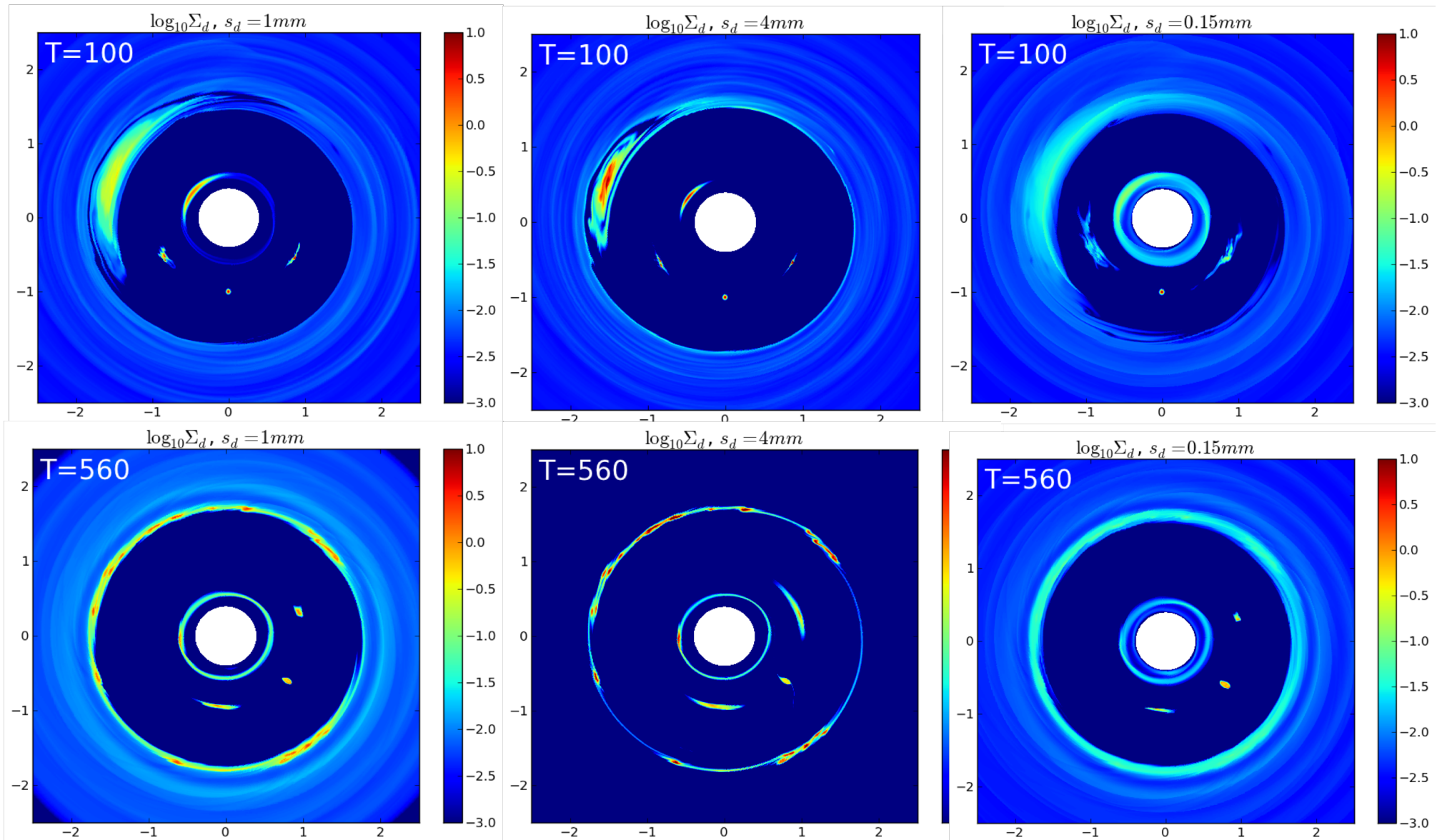
# Los Alamos COMPutational Astrophysics Simulation Suite(LA-COMPASS)

- Navier-Stokes equations are solved with 3D spherical grid
- Accelerated time integration by semi-Lagrangian approach in azimuthal direction: improve the time step size by  $\sim 30$  times
- Multiscale time solver for coupled gas & dust dynamics, bridging time scales over 20 magnitude
- Semi-Lagrangian AMR: bridging local spatial resolutions
- MPI + OpenMP + OpenACC: high-efficiency hybrid parallelization

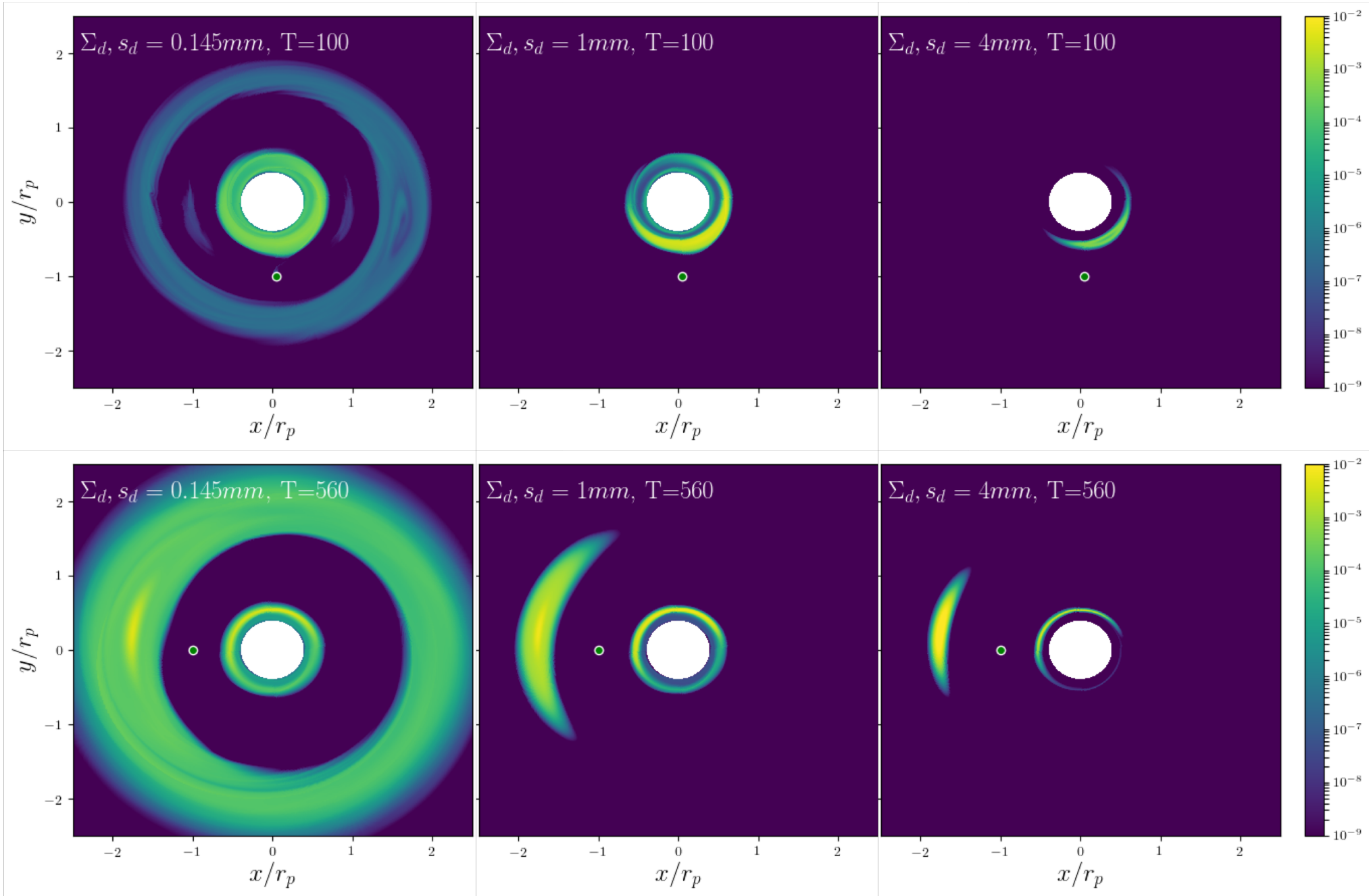
# The Coupling between Hydro of LA-COMPASS and Dust Coagulation

- We adopt a dust growth model of Birnstiel et al (2010).
- Operator-split approach:
  - One dust coagulation step corresponds to tens of hydro steps
  - Mass and momentum conservation during the coagulation step
  - Time synchronize
- Speed up using OpenMP + MPI + OpenAcc

# Dust Feedback in Destroying Rossby Vortex Instability (RVI) in Disk-Planet Interaction



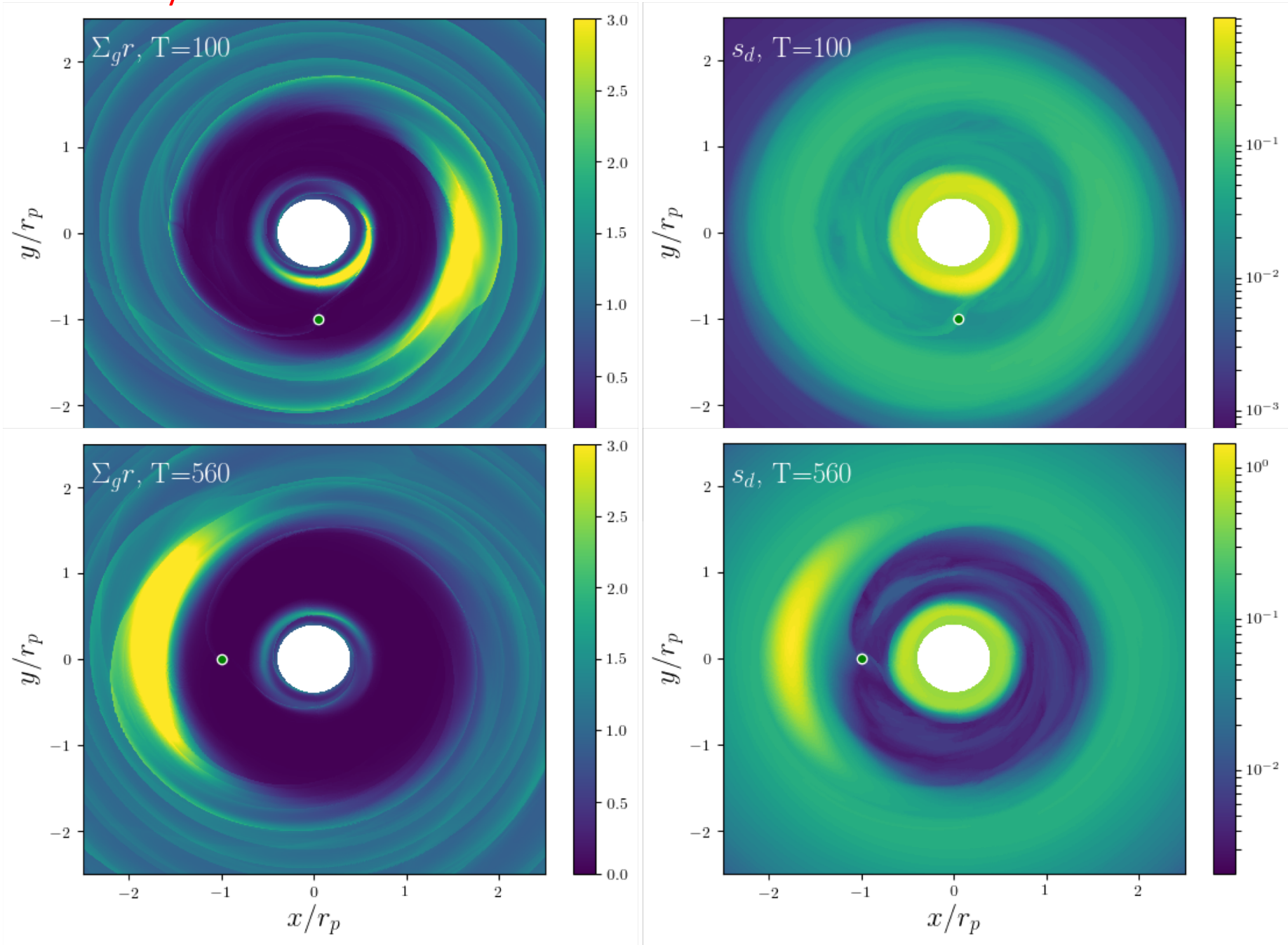
# Dust Coagulation for RVI



# Dust Coagulation for RVI

Gas density

Dust size distribution





# Conclusion

- We have implemented and tested dust coagulation with our hydro algorithm.
- The dust coagulation greatly reduces the dust feedback to gas dynamics, and enhance the Rossby vortex can be maintained for a long time.
- The planetesimals can be generated at the vortex.